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(54) **CARBON DIOXIDE RECIRCULATION**

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F02C 7/00 (2006.01)

(52) **U.S. Cl.** **60/39.52; 60/784**

(58) **Field of Classification Search** 60/39.52, 60/772, 783, 784, 801, 39.5
See application file for complete search history.

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(57) **ABSTRACT**

Carbon dioxide recirculating apparatus (20, 120) is disclosed for use in an arrangement having combination means (115) and a path for the flow of a gas through the combustion means (115). The apparatus (20, 120) comprises extraction means (221) for extracting carbon dioxide from a first region of the path downstream of the combustion means (115). It further includes condensing means (26, 30) for condensing the extracted carbon dioxide, and feed means (36, 136) for feeding the condensed carbon dioxide to a second region of the path upstream of the combustion means.

9 Claims, 4 Drawing Sheets

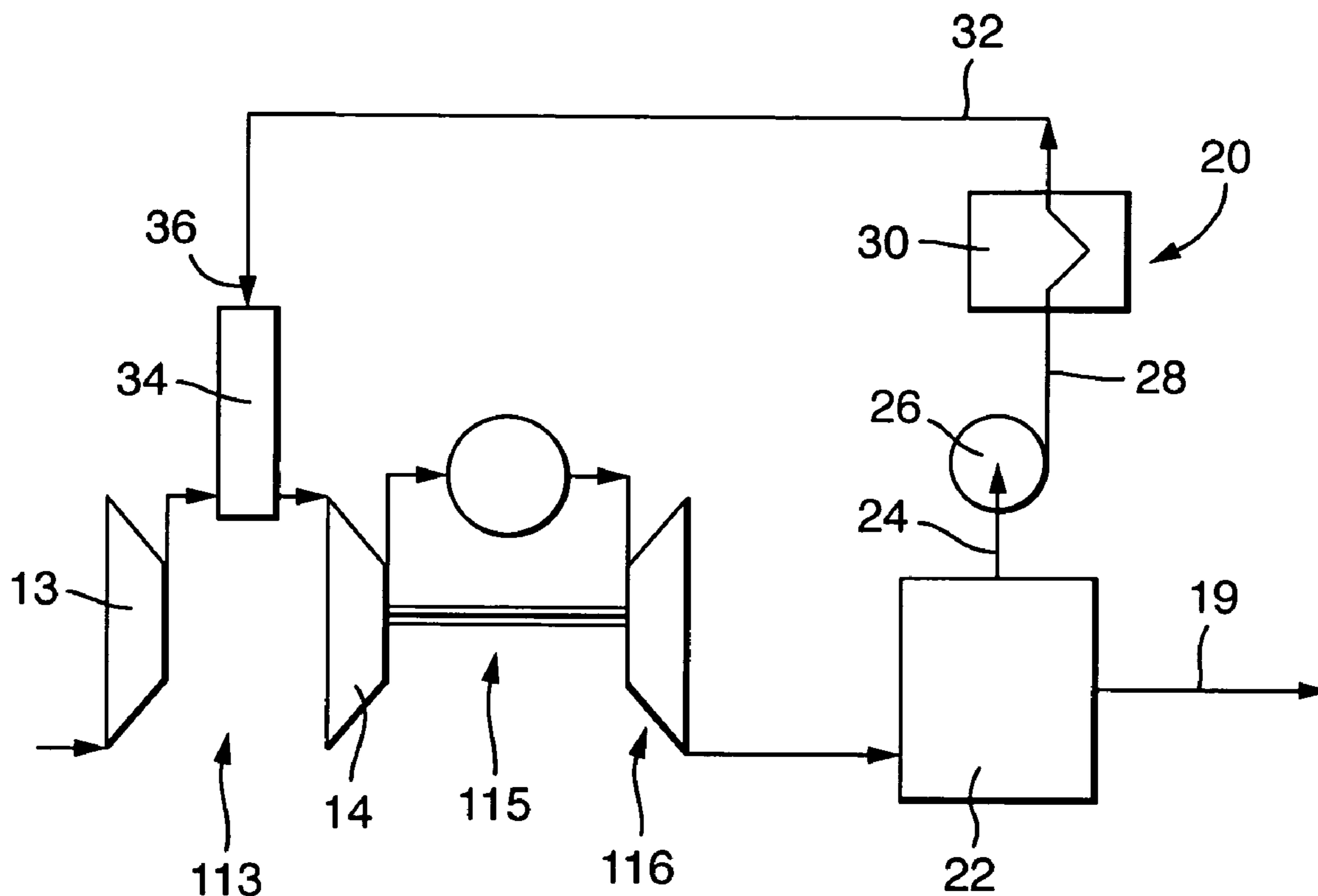


Fig. 1.

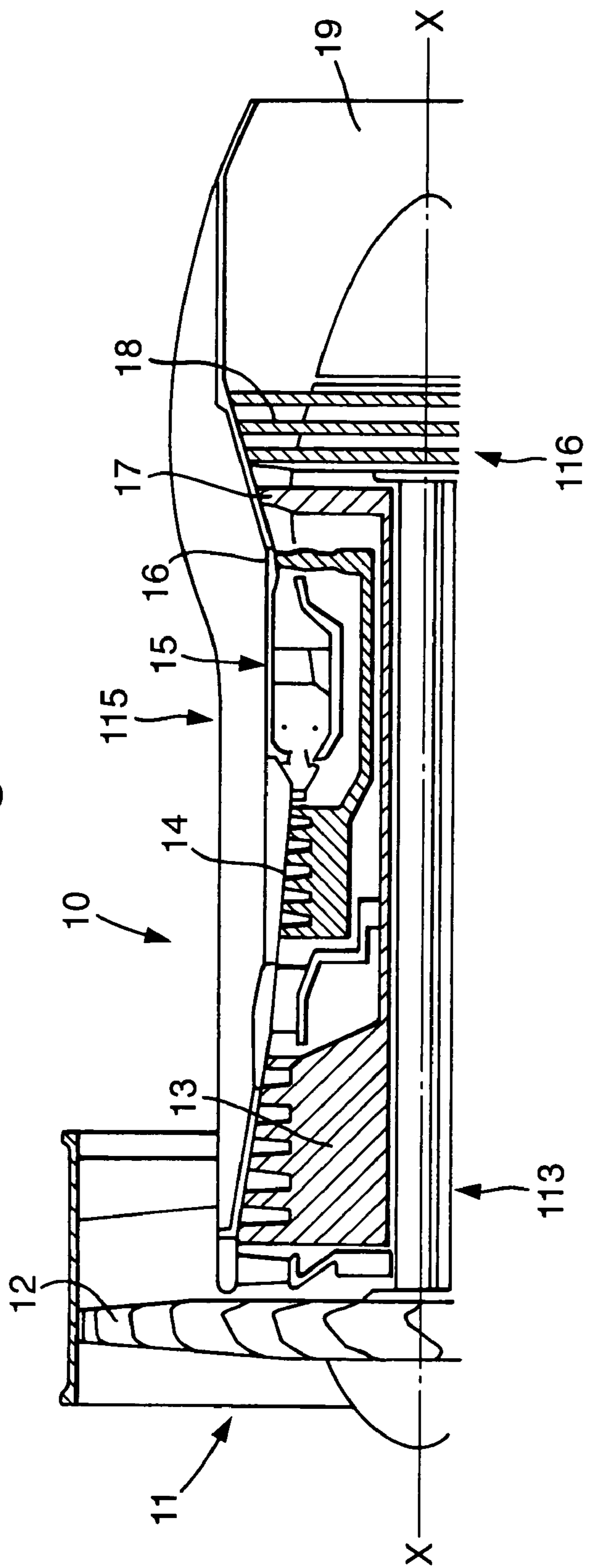


Fig.2.

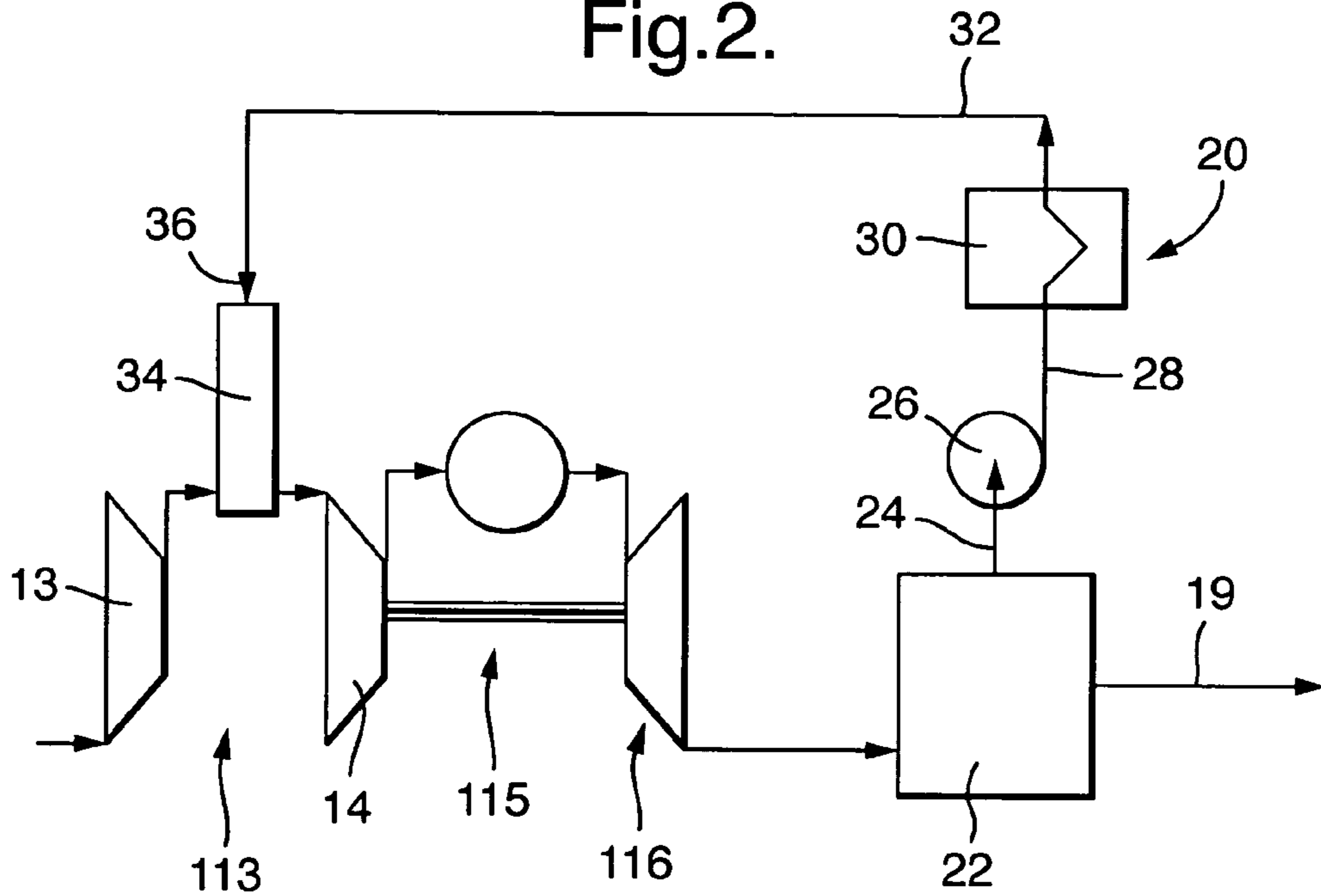


Fig.3.

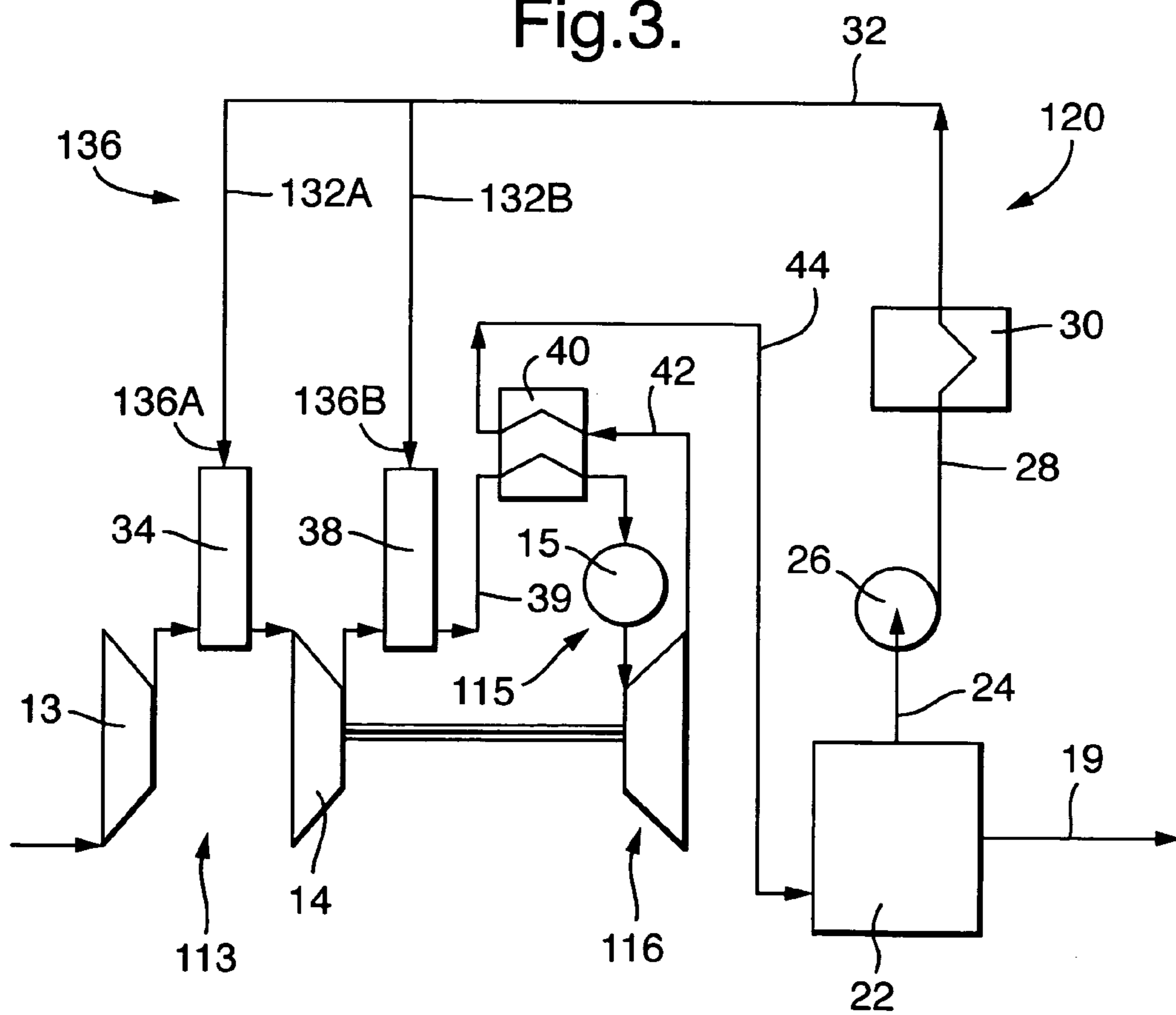


Fig. 4.

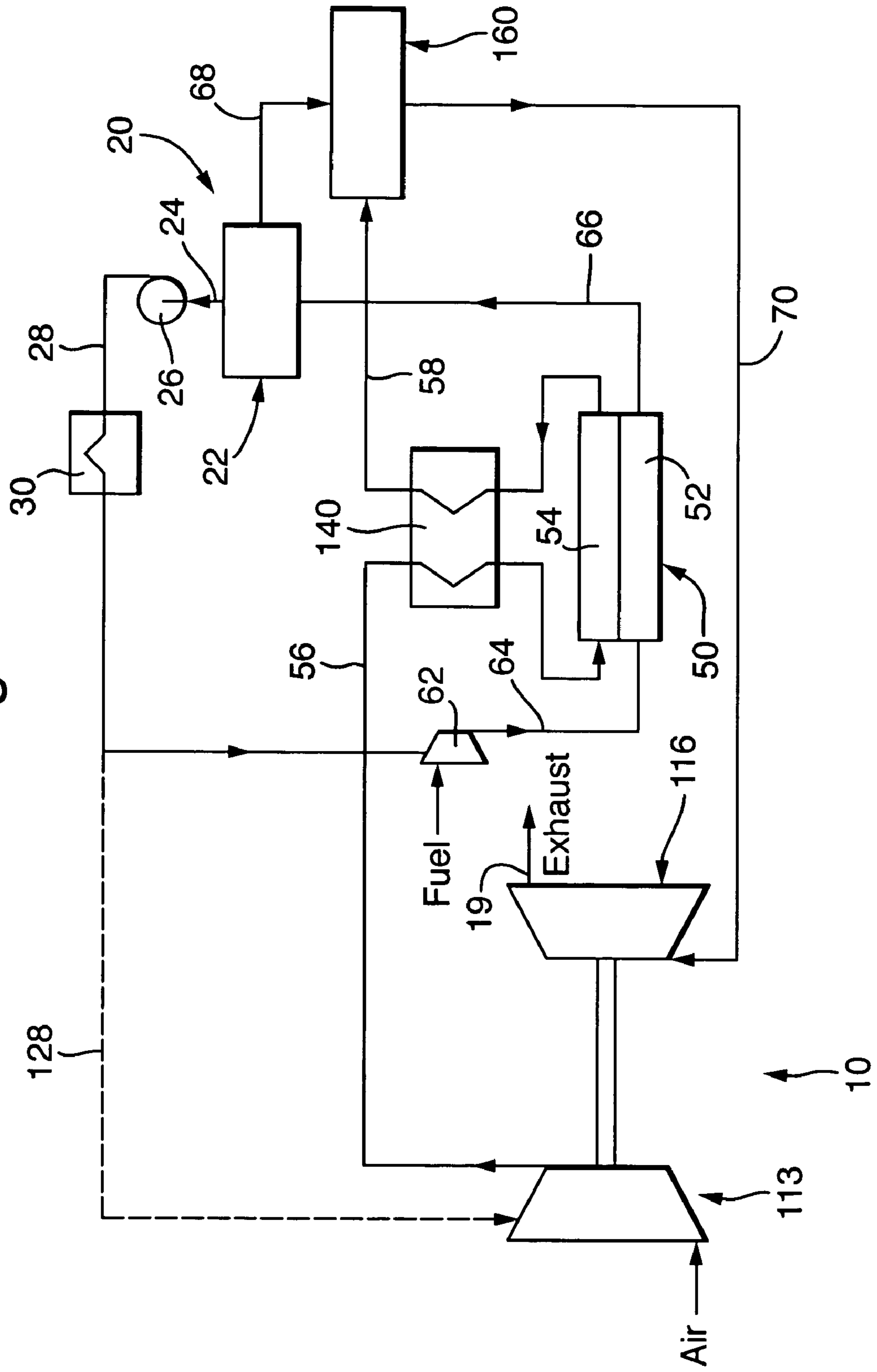
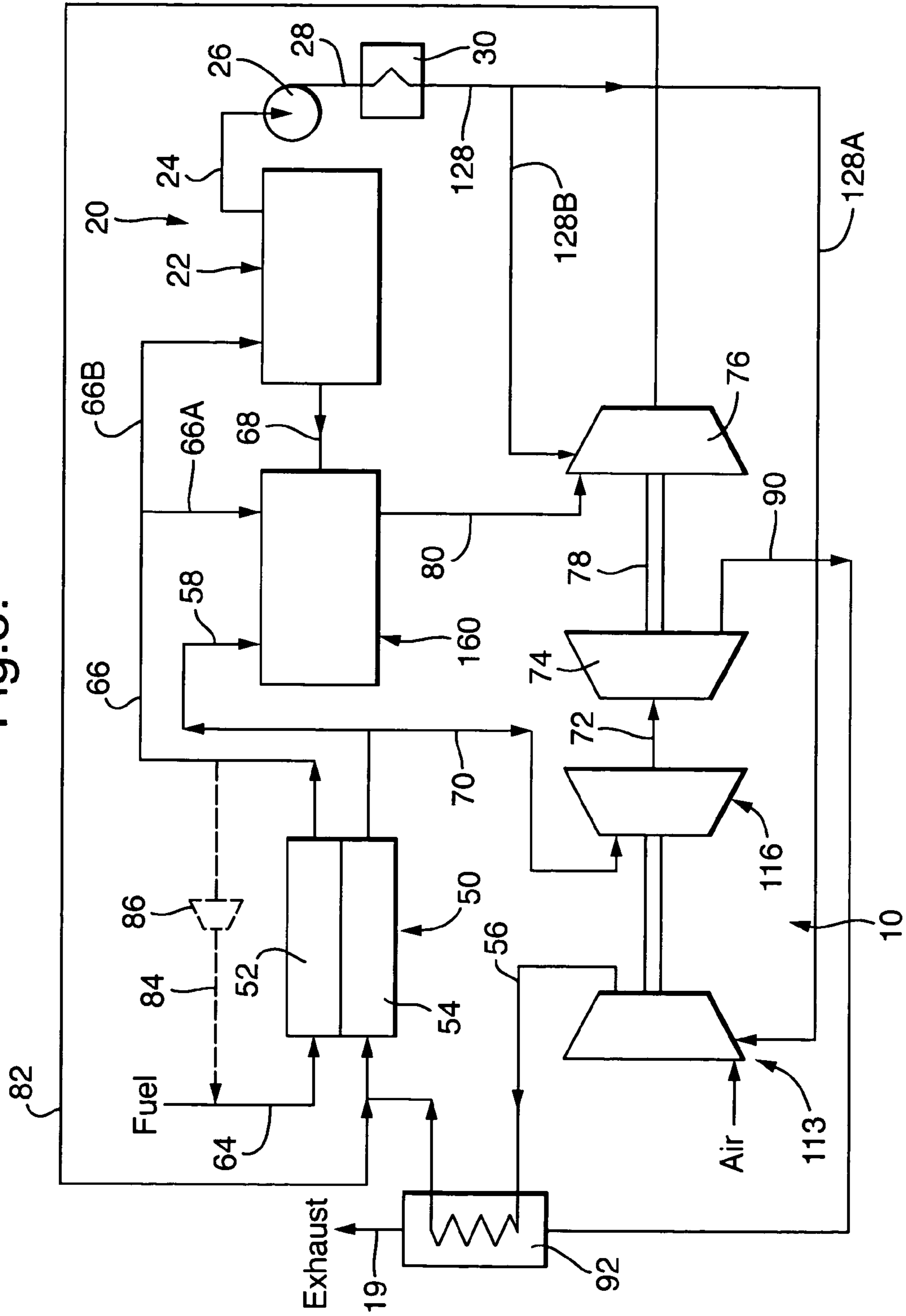


Fig. 5.



CARBON DIOXIDE RECIRCULATION

This is a Divisional Application of National Application Ser. No. 10/829,433 filed Apr. 22, 2004 now U.S. Pat. No. 7,377,111.

TITLE OF THE INVENTION

1. Field of the Invention

This invention relates to carbon dioxide recirculating apparatus. More particularly, the invention relates to carbon dioxide recirculating apparatus for heat engines, for example gas turbine engines, or fuel cells.

2. Background of the Invention

It is known to inject a water based fog into the compressor region of a gas turbine engine to increase the power of the engine. The water is atomised when it is sprayed into the compressor region and forms a fog. The water droplets forming the fog vaporise and extract latent heat of evaporation from the gases in the compressor, thereby cooling these gases. This has a beneficial affect on the power output of the engine. A disadvantage of such a system is that evaporation of the water droplets is not readily achieved and requires onerous nozzle and spray pressure specifications to achieve the required cooling effect.

SUMMARY OF THE INVENTION

According to one aspect of this invention, there is provided carbon dioxide recirculating apparatus for an arrangement comprising combustion means and a path for a flow of gas through the combustion means, the apparatus comprising extraction means for extracting gaseous carbon dioxide from a region of the path downstream of the combustion means, condensing means for condensing the extracted carbon dioxide, and feed means for feeding the condensed carbon dioxide to a region of the path upstream of the combustion means.

The arrangement preferably comprises a heat engine or a fuel cell.

The preferred embodiment of the invention is particularly suitable for use in an arrangement in the form of a gas turbine engine. In this embodiment, the feed means may feed the condensed carbon dioxide to a compressor region of the gas turbine engine. The extraction means may be arrangeable downstream of a turbine arrangement of the gas turbine engine.

According to another aspect of this invention there is provided an arrangement comprising combustion means a path for the flow of gas through the combustion means and carbon dioxide recirculating apparatus comprising extraction means for extracting gaseous carbon dioxide from a first region of the path downstream of the combustion means, condensing means for condensing the extracted carbon dioxide, and feed means for feeding the condensed carbon dioxide to a second region of the path upstream of the combustion means.

The arrangement may comprise a heat engine or a fuel cell assembly. The heat engine may be a gas turbine having a compressor region in the path of the gas upstream of the combustion means, and a turbine region in the path of the gas downstream of the combustion means. The compressor means may be a compressor unit.

The condensing means may comprise heat removal means to remove heat from the extracted carbon dioxide. The condensing means may include compressor means to compress the extracted carbon dioxide. Preferably, the compressor means is arranged between the extraction means and the heat

removal means. In the preferred embodiment, the heat removal means comprises cooling means to cool the carbon dioxide.

The feed means may comprise spray means to spray the condensed carbon dioxide into the second region. Where the arrangement comprises a gas turbine engine, the spray means may spray the condensed carbon dioxide into the compressor region of the gas turbine engine, preferably to form a fog of the carbon dioxide. The spray means may comprise atomising means, which may be in the form of a nozzle. Preferably, the atomising means comprises a plurality of atomising nozzles, which may be in the form of an array of nozzles.

The extraction means may comprise a recirculating amine based extraction means, and may include cooling and heating units to support the operation of the amine based extraction means.

Preferably, the extraction means is arrangeable to extract carbon dioxide from the exhaust gases downstream of the turbine region.

The compressor region of the engine may comprise first and second compressors, and the feed means may be arrangeable to feed condensed carbon dioxide to the compressor region between the first and second compressors. Alternatively, or in addition, the feed means may feed the condensed carbon dioxide to the compressor region at an outlet of the compressor region. Alternatively, or in addition, the feed means may be arrangeable to feed the carbon dioxide at an inlet to the compressor region.

In one embodiment, the feed means may be arrangeable to feed the condensed carbon dioxide to the outlet of the compressor region, whereby the carbon dioxide thereafter passes into a heat exchanger to exchange heat with gases exiting from the turbine region of the gas turbine engine. Preferably, the heat exchanger comprises a recuperator.

The fuel cell assembly may be arranged to receive carbon dioxide from the carbon dioxide recirculating apparatus. The fuel cell assembly may comprise an anode and a cathode. Preferably exhaust from the anode is passed to the carbon dioxide recirculating apparatus.

The fuel cell assembly may comprise a compressor for compressing air and other gases to be supplied to the cathode. The fuel cell assembly may comprise a conduit for directing recirculated carbon dioxide to the anode. Alternatively, or in addition, the fuel cell assembly may comprise a conduit for directing carbon dioxide to the compressor for mixing with air compressed by the compressor. The compressor may be a compressor of the compressor region of the gas turbine engine.

According to another aspect of this invention, there is provided a method of recirculating carbon dioxide from a flow of gas through an arrangement comprising combustion means and a path for the flow of gas through the combustion means, the method comprising extracting carbon dioxide from a first region downstream of the combustion means, condensing the extracted carbon dioxide and thereafter feeding the condensed carbon dioxide to a second region upstream of the combustion means.

Preferably the step of condensing the extracted carbon dioxide comprises providing heat removal means to remove heat from the carbon dioxide and may also include compressing the carbon dioxide prior to removing said heat from the carbon dioxide.

The heat removal means may comprise cooling means to cool the carbon dioxide to effect said condensation thereof.

The step of feeding the condensed carbon dioxide to the second region of the engine may comprise spraying the condensed carbon dioxide to the second region. The spraying of the condensed carbon dioxide may form a fog of the carbon dioxide in the upstream region of the engine.

Preferably the step of feeding the carbon dioxide to the second region of the engine comprises atomising the condensed carbon dioxide.

In the preferred embodiment, the engine is a gas turbine engine comprising a compressor region upstream of the combustion means and a turbine region downstream of the combustion means, and the step of extracting carbon dioxide comprises extracting carbon dioxide downstream of the turbine region of the engine.

In the preferred embodiment, the step of feeding the carbon dioxide to the second region of the path comprises feeding the carbon dioxide to the compressor region of the engine. The compressor region may comprise first and second compressors arranged in axial flow series in the path and the step of feeding the carbon dioxide to the compressor region may comprise feeding the carbon dioxide between the first and second compressors and/or to an outlet of the compressor region and/or to an inlet of the compressor region.

The engine may comprise heat exchange means to exchange heat between gas entering the combustion means and gas exhausted from the combustion means, preferably downstream of the turbine region. The step of feeding the condensed carbon dioxide to the second region may comprise feeding the carbon dioxide to gas entering the heat exchange means upstream of the combustion means preferably at the outlet of the compressor region. The heat exchange means may comprise a recuperator.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings in which:

FIG. 1 shows a sectional view of the upper half of a gas turbine engine;

FIG. 2 is a diagrammatic representation of carbon dioxide recirculating apparatus;

FIG. 3 is a further diagrammatic representation showing another embodiment of carbon dioxide recirculating apparatus;

FIG. 4 is diagrammatic representation of a further embodiment of carbon dioxide recirculating apparatus incorporating fuel cell; and

FIG. 5 is a diagrammatic representation of another embodiment of carbon dioxide recirculating apparatus incorporating a fuel cell.

DETAILED DESCRIPTION OF THE INVENTION

With reference to FIG. 1, a ducted fan gas turbine engine generally indicated at **10** has a principal axis X-X. The engine **10** comprises, in axial flow series, an air intake **11**, a propulsive fan **12**, a compressor region **113** comprising an intermediate pressure compressor **13**, and a high pressure compressor **14**, combustion means **115** comprising a combustor **15**, and a turbine region **116** comprising a high pressure turbine **16**, an intermediate pressure turbine **17**, and a low pressure turbine **18**. An exhaust nozzle **19** is provided at the tail of the engine **10**.

The gas turbine engine **10** works in the conventional manner so that air entering the intake **11** is accelerated by the fan to produce two air flows: a first air flow into the intermediate pressure compressor **13** and a second air flow which provides propulsive thrust. The intermediate pressure compressor **13** compresses the air flow directed into it before delivering that air to the high pressure compressor **14** where further compression takes place.

The compressed air exhausted from the high pressure compressor **14** is directed into the combustor **15** where it is mixed with fuel and the mixture combusted. The resultant hot combustion products then expand through, and thereby drive, the high, intermediate and low pressure turbine **16**, **17** and **18** before being exhausted through the nozzle **19** to provide additional propulsive thrust. The high, intermediate and low pressure turbines **16**, **17** and **18** respectively drive the high and intermediate pressure compressors **14** and **13** and the fan **12** by suitable interconnecting shafts.

Referring to FIG. 2, there is shown a schematic representation of carbon dioxide recirculating apparatus **20** for use in a gas turbine engine. FIG. 2 shows the compressor region **113**, the combustion region **115**, and the turbine region **116**, of the engine **10** as described above. FIG. 2 also shows the carbon dioxide recirculating apparatus **20** comprising extraction means **22** arranged downstream of the turbine region **116** in the main flow of gas to be exhausted from the engine **10**. The extraction means **22** may comprise any suitable known carbon dioxide extraction arrangement. An example of such an arrangement is a recirculating amine based unit in which amine solvents such as diethandamine can be employed to remove the carbon dioxide to remove carbon dioxide from the gas in the main flow downstream of the turbine region **116**. Carbon dioxide extracted from the exhaust gases is passed via a line **24** to compressor means in the form of a carbon dioxide compressor unit **26**. The resulting carbon dioxide depleted exhaust is passed to the exhaust nozzle **19**.

The compressor unit **26** compresses the extracted carbon dioxide, which is passed via a line **28** to a cooler **30** which condenses the compressed carbon dioxide, and produces pressurized liquid carbon dioxide at or near ambient temperature. The pressurized liquid carbon dioxide is then passed via a line **32** to feed means in the form of a feed nozzle arrangement **36**. The pressurized liquid carbon dioxide is fed by the nozzle arrangement **36** to the compressor region **113** of the gas turbine engine **10**. Specifically, the liquid carbon dioxide is fed to the main duct designated **34** (shown schematically in FIG. 2) between the intermediate pressure compressor **13** and the high pressure compressor **14**.

The feed nozzle arrangement **36** comprises an array of atomising nozzles to spray the liquid carbon dioxide into the main duct **34** between the intermediate and high pressure compressors **13**, **14**.

As the liquid carbon dioxide is atomised into the duct **34**, it partly flashes to the vapour phase. Carbon dioxide which does not vaporise partly solidifies. This results in a mixture of solid, liquid and gaseous carbon dioxide. The solid carbon dioxide then sublimates to the vapour phase, and the remaining liquid carbon dioxide then vaporises to the vapour phase. This results in a carbon dioxide fog forming in the duct **34**. The sublimation and vaporisation of the carbon dioxide absorbs latent heat of sublimation and vaporisation from the gases in the duct **34** thereby cooling these gases.

FIG. 3 shows a further embodiment, which has many of the features of FIG. 2, and these features have been designated with the same reference numeral. In FIG. 3, the carbon dioxide recirculating apparatus is designated **120** and the feed

means is designated **136** and comprises a first feed nozzle arrangement **136A** and a second feed nozzle arrangement **136B**.

The line **32** carrying the pressurised liquid carbon dioxide at ambient temperature splits into a first line **132A** leading to the first feed nozzle arrangement **136A** and a second line **132B** leading to the second feed nozzle arrangement **136B**. The first feed nozzle arrangement **136A** atomises the liquid carbon dioxide so that it is sprayed into the duct **34** between the intermediate and high pressure compressors **13**, **14**. This spraying of the carbon dioxide has the same effects upon it as described above, with reference to the spraying of the carbon dioxide into the duct **34** in FIG. 2. The second feed nozzle arrangement sprays the liquid carbon dioxide into a duct **38** downstream of the high pressure compressor **14**, and upstream of the combustor region **115**. Again the carbon dioxide sprayed into the duct **38** undergoes the same phase changes as described above.

Thus, the pressurised liquid carbon dioxide sprayed into the ducts **34** and **38** via the respective arrays of nozzles **136A** and **136B** form a carbon dioxide fog in the ducts **34** and **38**.

A heat exchanger in the form of a recuperator **40** is provided in the embodiment shown in FIG. 3, to exchange heat between gases exiting the compressor region **113** and the gases exiting the turbine region **116**. The carbon dioxide fed by the second feed nozzle arrangement **136B** into the main flow of gas in the duct **38** flashes to the vapour phase, solidifies, sublimates and vaporises in the same way as described above with reference to FIG. 2. The carbon dioxide, along with other gases in the duct **38** is passed, as indicated by the arrow **39**, to one side of a recuperator **40** to exchange heat with exhaust gases from the turbine region **116** passed to the other side of the recuperator **40** as indicated by the arrow **42**. The recuperator **40** is provided to increase the heat in the gases entering the combustor **15**, which also has the effect of cooling the gases exiting from the turbine region **116** upstream of the extraction means **22**.

The exhaust gases from the turbine region **116** exit the recuperator **40** and are then passed to the carbon dioxide extraction means **22** via the main duct, as indicated by the arrow **44**.

FIG. 4 is a diagrammatic representation of carbon dioxide recirculating apparatus **20** incorporating a fuel cell **50**. The carbon dioxide recirculating apparatus **20** in FIG. 4 is shown in use in a gas turbine engine **10**. The features of the gas turbine engine **10** and the carbon dioxide recirculating apparatus **20** are given the same reference numerals as in FIG. 2.

The fuel cell **50** is, in the embodiment shown, a fuel cell of a type known generally as a solid oxide fuel cell. The fuel cell **50** comprises an anode **52** and a cathode **54**.

The compressor region **113** of the gas turbine engine **10** supplies compressed air to the cathode **54** via a recuperator **140** along a line **56**. In the anode **52**, the hydrogen in the fuel reacts with oxygen ions produced at the cathode **54** (as explained below) to produce water molecules and electrons creating an electric current. This is an exothermic reaction and the heat generated is transferred to the incoming compressed air in the line **56** in the recuperator **140**. The output from the cathode **54** is passed along a line **58** (via the recuperator **140**) to a combustor **160**. If desired the combustor **160** can be the combustor **15** of the engine **10**.

A fuel mixture (labelled FUEL in FIG. 4) is supplied to a supplementary compressor **62** which also received recirculated carbon dioxide from the carbon dioxide recirculating apparatus **20** (as explained below). The fuel mixture comprises fuel, hydrogen, carbon dioxide, carbon monoxide and

hydrocarbons and is compressed by the supplementary compressor **62** and fed via a line **64** to the anode **52** of the fuel cell.

The oxygen in the compressed air in the cathode **54** is electrically charged to provide oxygen ions. The oxygen ions pass through/across the solid oxide electrolyte membrane in the fuel cell **50** between the cathode **54** and the anode **52**, to react with the hydrogen in the anode **52** (as described above).

The exhaust products from the anode **52** are fed via a line **66** to the carbon dioxide extraction means **22**. The carbon dioxide is extracted from the exhaust products and passed via the line **24** to the carbon dioxide compressor unit **26** to be recirculated, via the cooler **30**, back to the supplementary compressor **62**.

The remaining exhaust products entering the carbon dioxide extraction means are passed to the combustor **160** along a line **68** and fed back to the turbine arrangement **116** of the engine **10** along a line **70**. This powers the turbine arrangement to drive the compressor arrangement **113**. The exhaust from the turbine arrangement **116** is exhausted to atmosphere via the exhaust nozzle **19**, (labelled EXHAUST).

As an alternative, or in addition, as shown in broken lines, the recirculated carbon dioxide flowing along the line **28** could be fed via a line **128** to the compressor arrangement **113**.

Another embodiment of a carbon dioxide recirculating apparatus **20** incorporating a fuel cell **50** is shown in FIG. 5. The carbon dioxide recirculating apparatus **20** is shown in use in a gas turbine engine **10**. The features of the gas turbine engine **10** and the carbon dioxide recirculating apparatus are given the same reference numerals as in FIG. 2.

The fuel cell **50** shown in FIG. 5 is of a type known as a molten carbonate fuel cell. In such a fuel cell **50** there is a requirement for carbon dioxide on the air/oxygen side of the fuel cell **50**, i.e. the cathode **54**.

The compressor region **113** receives recirculated carbon dioxide via line **128A** (as explained below), in addition to air. The compressed air and carbon dioxide is passed via the line **56** to the cathode **54** of the fuel cell **50**. Some of the reaction products from the cathode are passed via the line **58** to the combustor **160**. In some embodiments, the combustor **160** could be the combustor **15** of the gas turbine engine **10**.

The remainder of the reaction products from the cathode **54** are passed via a line **70** to the turbine arrangement **116**, which drives the compressor arrangement **113** as explained above. The exhaust **72** from the turbine arrangement **116** drives a free power turbine **74**, which, in turn, drives a further compressor **76** via a shaft **78**.

The exhaust from the free power turbine **74** is passed via a line **90** to a heat exchanger or recuperator **92** where heat is exchanged with compressed gases exiting from the compressor arrangement **113** prior to entering the cathode **54**.

After exiting the recuperator **92**, the gases from the free power turbine **74** are exhausted to atmosphere via the exhaust nozzle **19**.

The combustion products from the combustor **160** are passed via a line **80** to the further compressor **76**. The further compressor **76** also receives recirculated carbon dioxide (as explained above) via a line **128B**. The compressed combustion products and carbon dioxide are passed to the cathode **54** via a line **82**.

The anode **52** receives fuel via the line **64**. The reaction products pass from the anode **52** by a line **66**. Some of the reaction products may be recirculated via a line **84** and a supplementary compressor **86** to be passed back into the anode **52**.

The reaction products from the anode **52**, which are not recirculated, are split into two. Some of the reaction products

from the anode **52** are passed via a line **66A** to the combustor **160** and are mixed with the incoming reaction products from the cathode **54** and combusted. The remainder of the reaction products from the anode **52** are passed via a line **66B** to the carbon dioxide extraction means **22**.

The carbon dioxide is extracted and passed via the line **24** to the carbon dioxide compressor unit **26** and then cooled by the cooler **30**. The cooled carbon dioxide exits the cooler **30** via the line **128**. Some of the cooled carbon dioxide is passed via the line **128A** to the compressor arrangement **113**. The remainder of the cooled carbon dioxide is passed via the line **128B** to the compressor **76**, as described above.

The remaining cathode reaction products in the carbon dioxide extraction means **22** are passed via the line **68** to the combustor **160** to be combusted.

The above described embodiments have the advantage that the fog sprayed into the compressor region is formed from liquid carbon dioxide that flashes under more favourable and more easily achieved conditions than water. As a result, a fog with a small droplet size is generated more readily than with water. This results in there being less demanding nozzle and spray pressure specifications than are necessary with water.

Further, the above described embodiments have the advantage that the use of carbon dioxide means that complete evaporation of the fog can be more easily achieved than with water, due to the high saturated vapour pressure of the carbon dioxide at ambient temperatures. This permits the use of carbon dioxide based fog cooling to be used in conditions that would be too confined in length to achieve adequate evaporation with a water based fog. A further benefit is that carbon dioxide recirculation is achieved with less compression in the recirculating system than with a water based recirculation. It is possible thus to enhance efficiency and power of the engine more substantially than with the use of water.

The use of carbon dioxide has the further advantage that cooling could be carried out at the inlet of the compressors of a gas turbine engine, and could also be used in other engines, for example reciprocating engines. Indeed, the invention could be applied to a wide range of cycles using heat engines and/or fuel cells as the primary source of carbon dioxide.

Whilst endeavouring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

The invention claimed is:

1. Carbon dioxide recirculating apparatus for an arrangement having a compressor region upstream of a combustion

means, a turbine region downstream of said combustion means and an exhaust nozzle downstream of said turbine region, the apparatus being arranged to supply air to the compressor region and to supply fuel to the combustion means wherein said fuel is burned in said combustion means producing exhaust gases, the apparatus having means for extracting carbon dioxide from said exhaust gases from a first region downstream of the turbine region, condensing means for condensing the extracted carbon dioxide, and feed means for feeding the condensed carbon dioxide to a second region upstream of the combustion means without adding any constituent thereto, said second region comprising the compressor region.

2. Carbon dioxide recirculating apparatus according to claim **1** wherein the condensing means comprises heat removal means, to remove heat from the extracted carbon dioxide, and compressor means to compress the extracted carbon dioxide, the compressor means being arranged between the extraction means and the heat removal means.

3. Carbon dioxide recirculating apparatus according to claim **2**, wherein the heat removal means comprises cooling means to cool the compressed carbon dioxide.

4. Carbon dioxide recirculating apparatus according to claim **1**, wherein the feed means comprises spray means to spray the condensed carbon dioxide into the second region of the path to form a fog of the carbon dioxide.

5. Carbon dioxide recirculating apparatus according to claim **4**, wherein the spray means comprises atomising means.

6. Carbon dioxide recirculating apparatus according to claim **5**, wherein the atomising means comprises a nozzle.

7. An arrangement according to claim **1**, wherein the compressor region comprises first and second compressors arranged in a path in axial flow series, and the feed means is arranged to feed the condensed carbon dioxide to an outlet of the compressor region.

8. An arrangement according to claim **1**, wherein a heat exchanger is arranged to exchange heat between gas in a third region downstream of the compressor region and upstream of the combustion means and heat exhausted from the combustion means, and the feed means is arranged to feed at least some of the condensed carbon dioxide to the third region and downstream of the compressor region and upstream of the heat exchanger.

9. An arrangement according to claim **1**, wherein the compressor region comprises first and second compressors and the feed means is arranged also to feed some of the condensed carbon dioxide between the first and second compressors and/or to the inlet of the compressor region.

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